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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

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Applicant's or agent's file reference GB/13452.7	**FOR FURTHER ACTION** See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/CA 03/00486	International filing date (*day/month/year*) 02.04.2003	Priority date (*day/month/year*) 02.04.2002
International Patent Classification (IPC) or both national classification and IPC H02P21/00		
Applicant TURBOCOR INC. et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 5 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 16 sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the opinion
   II ☐ Priority
   III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   IV ☐ Lack of unity of invention
   V ☒ Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
   VI ☐ Certain documents cited
   VII ☐ Certain defects in the international application
   VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
16.10.2003	22.06.2004
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized Officer Kanelis, K Telephone No. +49 89 2399-7558

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/CA 03/00486

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:

   Description, Pages

   1-11 filed with telefax on 20.02.2004

   Claims, Numbers

   1-16 filed with telefax on 20.02.2004

   Drawings, Sheets

   1/2-2/2 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   - ☐ the description, pages:
   - ☐ the claims, Nos.:
   - ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)).

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-16
	No:	Claims	-
Inventive step (IS)	Yes:	Claims	1-16
	No:	Claims	-
Industrial applicability (IA)	Yes:	Claims	1-16
	No:	Claims	-

2. Citations and explanations

   see separate sheet

1). Following documents are referred to:
D1: EP0944164
D2: US5903128
D3: XP001003522 "TWO-DEGREE-OF-FREEDOM CONTROL OF A PMSM DRIVE WITHOUT MECHANICAL SENSOR" (1998)
D4: JP9285198

2). D1, which is considered as the closest prior art, discloses a
- system for controlling a permanent magnet electric motor (fig. 2, pp. 6, lines 22-24), comprising:
- a motor controller, that motor controller using phase currents (i_u, i_w) of the permanent magnet electric motor (8) to generate voltage controlling signals (6) in relation to changes in speed and torque of the permanent magnet electric motor (fig. 1, pp. 4, lines 25, 26, pp. 5, line 4 and lines 30-40),
- the power stage (7) is receiving the voltage controlling signals from the motor controller and feeding them back to the permanent magnet electric motor (fig.2)

3). Claim 1 is distinguished from D1 in that the controller
- generates voltage controlling signals in relation to both changes in speed and torque.

4). The prior art always uses the induced voltage, also called back EMF, for the rotor angle position detection. The induced voltage is either measured, as usual, or estimated, as in D1. Thus, the skilled person, trying to calculate his rotor position angle, would apparently use the induced voltage and would not have any reason to replace this quantity by the calculated torque.

Since D1 also responds to changes in torque, but the reference torque, which is proportional to the reference current $i_{\delta REF}$, it is recommended to specify in claim 1: "both changes in *measured* speed and *estimated* torque".

With this difference, claim 1 would appear as new and inventive (Art. 33(2) and (3) PCT).

5). Claim 5 proposes a corresponding method for calculating the rotor position angle, and is therefore also new and inventive (Art. 33(2) and (3) PCT).

6). Claims 2-4 and 6-16 define details of the controller and the algorithm and are also

new and inventive (Art. 33(2) and (3) PCT).

7). Independent device claim 14 does not appear as inter-related to claim 1, since it explains in more detail, how changes in speed and torque are used to derive control signals. The "circuit" in claim 14 seems to be the "system" in claim 1, since both are controlling the motor. It is therefore recommended to formulate claim 14 as depending on claim 1. The same holds true for method claims 15 and 16 with respect to claim 5.

TITLE OF THE INVENTION

System and method for controlling a permanent magnet electric motor.

FIELD OF THE INVENTION

[0001] The present invention relates to permanent magnet electric motors. More precisely, the present invention is related to a system and a method for controlling a permanent magnet electric motor.

BACKGROUND OF THE INVENTION

[0002] Generally, in order to control a permanent magnet motor, characteristics of the permanent magnet motor such as the phase, the frequency and the amplitude of the electric motive force ("emf") voltage generated by the rotation of the motor rotor, need to be determined to yield a voltage to be applied to the motor terminals.

[0003] These characteristics of the permanent magnet motor may be obtained by using a position sensor, which results in increased costs and reduces the reliability of the method because feedback signals are subject to changes in the ambient environment such as noise and temperature and to the presence of impurity for example.

[0004] A possible method involves estimating the emf of the permanent magnet motor. However, in case of a high-speed motor this method requires a high computation speed, which may result costly. Moreover, since the characteristics of the motor are dependent on the ambient environement, such a control method can be complex.

[0005] From the foregoing, it appears that although a number of methods are known to control permanent magnet motors, these methods either require position sensors and complicated computation or must be adapted to the environment according to each design of permanent magnet motors.

[0006] Therefore, there is a need for a system and a method, which allow controlling a permanent magnet electric motor in a simple, reliable way and which automatically adapts to environmental changes.

OBJECTS OF THE INVENTION

[0007] An object of the present invention is therefore to provide an improved controller system and method for a permanent magnet electric motor.

SUMMARY OF THE INVENTION

[0008] More specifically, in accordance with the present invention, there is provided a system for controlling a permanent magnet electric motor, comprising a motor controller and a power stage, the motor controller using phase currents of the permanent magnet electric motor to generate voltage-controlling signals in relation to both changes in speed and torque of the permanent magnet electric motor, which are fed back to the permanent magnet electric motor via the power stage.

[0009] Moreover, there is provided a method for controlling a permanent magnet electric motor comprising determining a current of each phase of the permanent magnet electric motor; obtaining voltage controlling signals in relation to both changes in speed and torque of the permanent magnet electric motor; and feeding the voltage controlling signal back to the permanent magnet electric motor.

[0010] There is further provided a circuit for controlling a permanent magnet three-phases electric motor provided with a rotor and a stator, comprising a rotator allowing rotation of current signals of the phases of the permanent magnet electric motor from a stationary frame to two decoupled current components in a rotor synchronous frame along a direct axis (I_d) and a quadrature axis (I_q) respectively; a proportional and integral operator for deriving a voltage (V_q) along the quadrature axis and a voltage (V_d) along the direct axis; a rotator allowing rotating the voltages V_q and V_d back from the rotor synchronous frame to the stationary frame to yield terminal voltages V_a, V_b and V_c of the permanent magnet electric motor.

[0011] There is still further provided a method for controlling a permanent magnet three-phases electric motor provided with a rotor and a stator, comprising rotating current signals of the phases of the permanent magnet electric motor from a stationary frame to two decoupled current components in a rotor synchronous frame along a direct axis (I_d) and a quadrature axis (I_q) respectively; deriving a voltage (V_q) along the quadrature axis therefrom; deriving a voltage (V_d) along the direct axis; rotating the voltages V_q and V_d back from the rotor synchronous frame to the stationary frame to yield terminal voltages V_a, V_b and V_c of the permanent magnet electric motor.

[0012] There is also provided a method for controlling a permanent magnet electric motor having three-phases each supporting a current i_a, i_b and i_c respectively, comprising determining the currents i_a, i_b and i_c; rotating the currents i_a, i_b and i_c by an angle $-\theta_n$ to yield currents I_d and I_q; computing a current torque of the permanent magnet electric motor; computing a current rotating angle θ_{n+1}; computing a voltage output V_q; computing a voltage output V_d; rotating the voltages Vq and V_d by the rotating angle θn+1 to yield three

voltage controlling signals V_a, V_b and V_c; and applying the voltage controlling signals V_a, V_b and V_c to the permanent magnet electric motor.

[0013] Other objects, advantages and features of the present invention will become more apparent upon reading of the following non-restrictive description of embodiments thereof, given by way of example only with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] In the appended drawings:

[0015] Figure 1 is a simplified diagram of a motor controller system according to an embodiment of a first aspect of the present invention; and

[0016] Figure 2 is a flowchart of a method for controlling an electric motor according to an embodiment of a second aspect of the present invention.

DESCRIPTION OF THE EMBODIMENT

[0017] Generally stated, the present invention provides a system and method for controlling a three-phased electric motor, by monitoring the terminal voltages thereof in relation to both changes in speed and torque of the motor.

[0018] More specifically, the present invention provides that the phase currents of a permanent magnet electric motor are first rotated from a stationary frame into two decoupled current components in a rotor synchronous frame, which enable to derive a voltage along a quadrature axis and a voltage

along a direct axis thereof, before rotating back the quadrature and direct axis voltages from the rotor synchronous frame to the stationary frame to yield the motor terminal voltages.

[0019] The system 10 shown in Figure 1 comprises a permanent magnet motor, referred to hereinafter as PM motor 12; a power stage 14; and a motor controller 16.

[0020] The PM motor 12 is a three-phase electric motor provided with a rotor and a stator (not shown), each one of the phases carrying a current, i_a, i_b and i_c, respectively. These phases currents are sensed and used by the park vector rotator unit 16 to generate three voltage-controlling signals V_a, V_b and V_c, which are then supplied to the power stage 14.

[0021] For example, the power stage 14 may be of the type provided by Semikron, in particular the SKiiPACK™ 342 GD 120-314 CTV for example.

[0022] The angular speed "ω" of the motor is controlled by a user by setting a value representing the speed of the PM motor 12 into the system 10. The user chooses a reference current value "I*", normally set at 0, but other values may be selected.

[0023] The motor controller 16 is in the form of a park vector rotator unit. The park vector rotator unit 16 generates two continuously rotating angles having instantaneous values θ_{n+1} and $-\theta_n$, wherein the negative sign represents an opposite direction of rotation, the subscript "n+1" labels a current computing angle, and the subscript "n" labels the previous computing angle.

[0024] For clarity purposes, the main steps of a method for controlling a permanent magnet electric motor using the system 10 according to a second aspect of the invention will now be described in reference to Figure 2.

[0025] In a first step 100, the three currents i_a, i_b and i_c, from the three phases of the PM motor 12 are determined by the use of standard current sensors.

[0026] Then, in a following step (200), the three currents i_a, i_b and i_c are processed in an inverse park vector rotator 18, which rotates them by an angle $-\theta_n$, to output two currents I_d and I_q.

[0027] In step 300, the two currents I_d and I_q are used to compute a current torque "T" of the PM motor 12, which is in turn used to compute the current rotating angle θ_{n+1} (step 400).

[0028] Additionally, the two currents I_d and I_q are used to compute two voltage outputs V_q and V_d (steps 500 and 600). The voltage outputs V_q and V_d are then rotated in a park vector rotator 20 by the rotating angle θ_{n+1} to yield three voltage controlling signals V_a, V_b and V_c (step 700).

[0029] Returning now to Figure 1, the steps of the method of the present invention will now be described in more details.

[0030] The current computing angle is derived in response to changes of the speed ω and of the torque T of the PM motor 12 from the following equation:

$$\theta_{n+1} = \theta_n + k_1 \times \omega + k_2 \times T \quad (1)$$

where k_1 and k_2 are constants.

[0031] As seen in Figure 1, the phase currents i_a, i_b and i_c are directed through lines 12a, 12b and 12c to a first inverse park vector rotator 18, which rotates them by the angle $-\theta_n$, to output the two currents I_d and I_q, according to the following relations on the d-q axis fixed on the rotor axis:

$$I_d = 2/3 \times [i_a \times \cos(\theta_n) + i_b \times \cos(\theta_n + 120°) + i_c \times \cos(\theta_n - 120°)] \quad (2)$$

$$I_q = 2/3 \times [i_a \times \sin(\theta_n) + i_b \times \sin(\theta_n + 120°) + i_c \times \sin(\theta_n - 120°)] \quad (3)$$

[0032] It is to be noted that either the three currents i_a, i_b and i_c from the three phases of the PM motor 12 are measured, or only two of them, the third phase current being calculated from the other two phases since, as is known in the art, the following relation holds:

$$\sum_{\textit{three phases}} i = 0 \quad (4)$$

[0033] The I_d and I_q rotated values are further used to generate a first voltage output V_q which takes into account an error between the preset value I^* and I_d, according to the following equation on the d-q axis fixed on the rotor axis:

$$V_q = PI\,(I^* - I_d) + k_3 \times I_q \quad (5)$$

where k_3 is a constant, "PI" refers to a proportional and integral operator, defined as follows:

$$PI(x) = ax + b\int x\, dt \quad (6)$$

where a and b are constants and the integration is over time.

[0034] The I_d and I_q rotated values are also used to generate the second voltage output V_d, according to the following equation on the d-q axis fixed on the rotor axis:

$$V_d = k_5 \times I_d + k_4 \times I_q \times \omega \quad (7)$$

where k_4 and k_5 are constants.

[0035] Moreover, the speed ω is set by the user as stated hereinabove, whereas the torque T can be calculated by the following formula:

$$T = (V_d \times I_d + V_q \times I_q) / \omega \quad (8)$$

using the I_d and I_q currents and V_d and V_q on the d-q axis fixed on the rotor frame, as determined hereinabove by equations (2)-(3).

[0036] The two voltages V_d and V_q in the continuously rotating reference frame are then submitted to a second park vector rotator 20, whereby they are rotated by the angle θ_{n+1}, to produce three voltage controlling signals, namely V_a , V_b and V_c, which control the power unit 14, according to the

following equations:

$$V_a = V_d \times \cos(\theta_{n+1}) + V_q \times \sin(\theta_{n+1}) \quad (9)$$

$$V_b = V_d \times \cos(\theta_{n+1}+120°) + V_q \times \sin(\theta_{n+1}+120°) \quad (10)$$

$$V_c = V_d \times \cos(\theta_{n+1}-120°) + V_q \times \sin(\theta_{n+1}-120°) \quad (11)$$

[0037] It is to be noted that the values k_1 to k_5 are constants that the user sets, when designing the system 10, based on a number of parameters, including the sampling rate of the computer to be used, condition of the power drive, sensitivity of the current sensors, the characteristics of the motor etc....

[0038] From the foregoing, it should be apparent that the present invention provides for a system and a method whereby the motor terminal voltages are self-adapting. More specifically, three current signals are first rotated from a stationary frame to two decoupled current components in a rotor synchronous frame, along a direct axis (I_d) and a quadrature axis (I_q) respectively. Then, on the first hand, a voltage (V_q) along the quadrature axis is derived therefrom, by applying a proportional and integral operator on the direct axis current component added with a product of a constant and the current components along the quadrature axis (see equation 5). On the other hand, a voltage (V_d) along the direct axis is derived, as a product of the direct axis current component added to a product of the speed of the motor by the quadrature current component (see equation 7). Finally, the quadrature and direct axis voltages (V_q and V_d) thus computed are rotated back from the rotor synchronous frame to the stationary frame to yield the motor terminal voltages (V_a, V_b and V_c, see equations 9-11).

[0039] Therefore, the present system and method allow for a continuously updating value of the angle in response to changes of speed and variations in the torque as well as to changes in ambient conditions.

[0040] From the foregoing, it is now also apparent that the present invention provides a circuit for controlling a permanent magnet three-phases electric motor provided with a rotor and a stator, comprising a rotator allowing rotation of current signals of the phases of the permanent magnet electric motor from a stationary frame to two decoupled current components in a rotor synchronous frame along a direct axis (I_d) and a quadrature axis (I_q) respectively; a proportional and integral operator for deriving a voltage (V_q) along the quadrature axis and a voltage (V_d) along the direct axis; a rotator allowing rotating the voltages V_q and V_d back from the rotor synchronous frame to the stationary frame to yield terminal voltages V_a, V_b and V_c of the permanent magnet electric motor.

[0041] In particular, people in the art will appreciate that the method and system of the present invention allows controlling a permanent magnet motor without resorting to position sensors or characteristics of the permanent magnet motor such as the emf, which are liable to depend on the environment, thereby adaptable to environmental conditions.

[0042] Although the present invention has been described hereinabove by way of specific embodiments thereof, it can be modified, without departing from the spirit and nature of the subject invention as defined in the appended claims.